DOE S&T Review
7 July 2005
G. Bunce

Spin Physics Group

…to study the spin structure of the proton

- Manpower and current support
- Science and priorities: RHIC Spin Plan
- Accomplishments: including RHIC polarimetry
- Plans
- Issues

Manpower and current support

STAR: Les Bland (tenured) **Group Support: $1700K**
Akio Ogawa (Assoc. Physicist)
Greg Rakness (Res. Associate/Penn State)

PHENIX: Gerry Bunce (Group Leader; tenured)
Alexander Bazilevsky (Assoc. Physicist)
+ RBRC (5 Fellows, 2 RAs)

Polarimetry: Sandro Bravar (leads polarimetry; Physicist; also STAR)
Ron Gill (50% with Physics Dept. safety; continuing)
+ RBRC, Kyoto, CAD, Yale (**WFD contract $122K**), Instrumentation Div.

Pp2pp: Wlodek Guryn (Spokesman; expt. complete; continuing)

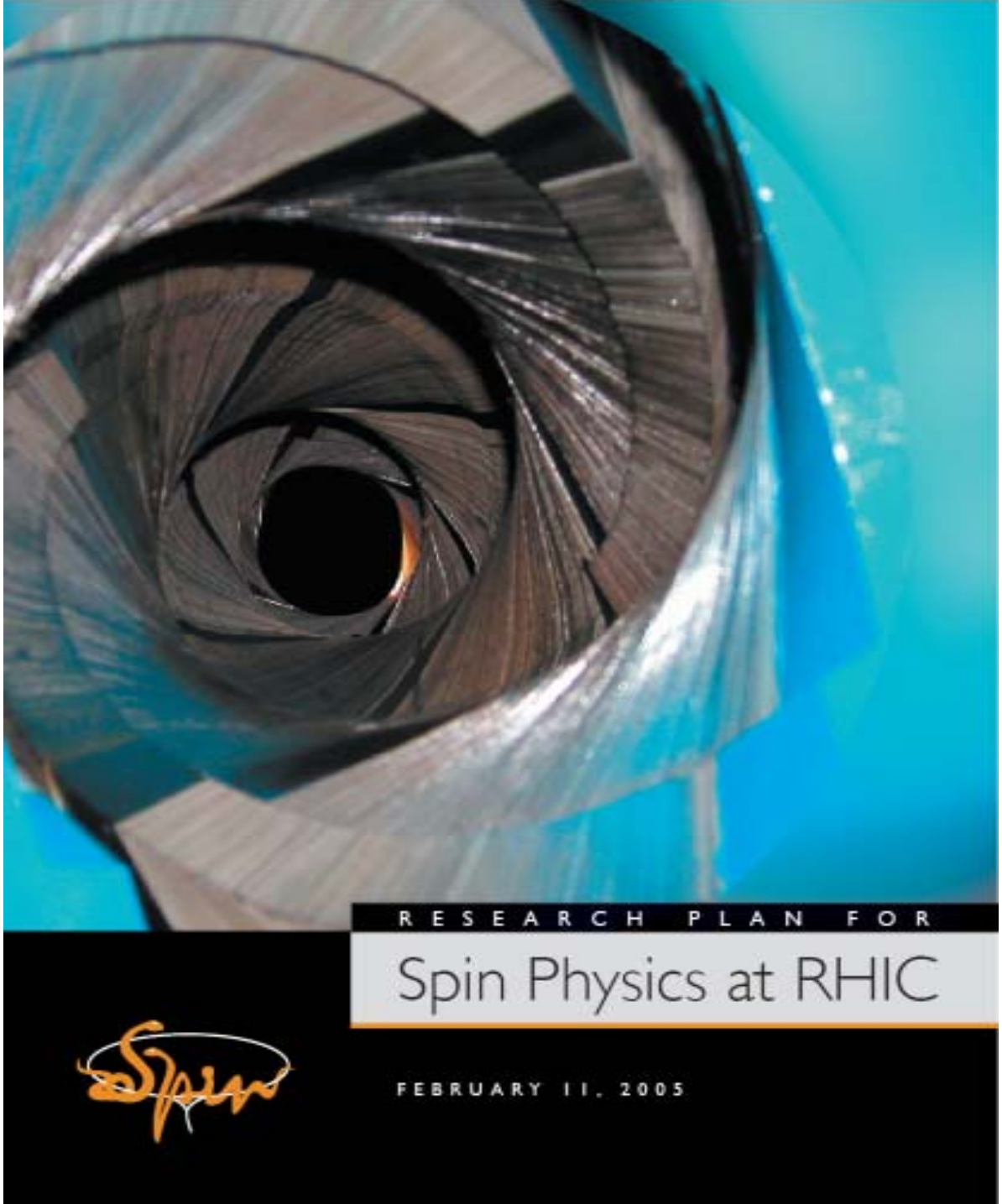
Secretary: Melanie Echmalian (50% with Brahms)

Science and Priorities

Developed RHIC Spin Plan

---response to action item of 2004 S&T Review

- Science
- Experiment upgrades for W program
- Accelerator Requirements and time evolution


RESEARCH PLAN FOR
Spin Physics at RHIC
FEBRUARY 11, 2005

Spin is one of the most fundamental concepts in physics, deeply rooted in Poincare invariance and hence in the structure of space-time itself. All elementary particles we know today carry spin, among them the particles that are subject to the strong interactions, the spin ½ quarks and the spin 1 gluons. Spin, therefore, plays a central role also in our theory of the strong interactions, QCD, and to understand spin phenomena in QCD will help to understand QCD itself.

To contribute to this understanding is the primary goal of the spin physics program at RHIC.

a history of the strong interaction:

1964: **"quarks" …to understand the zoo of strongly interacting particles; "color" quantum number …to describe the Ω-** (sss, S=3/2)

1967: **quarks are real! …from hard inelastic scattering of electrons from protons at SLAC**

1973: **the theory of QCD …quarks and "gluons" and color; *perturbative* QCD**

1980s to present: **e-p and pbar-p colliders …beautiful precision tests of pQCD, *unpolarized***

……

1970s: *polarized* beams and targets

1988: **the spin of the proton is not carried by its quarks!**

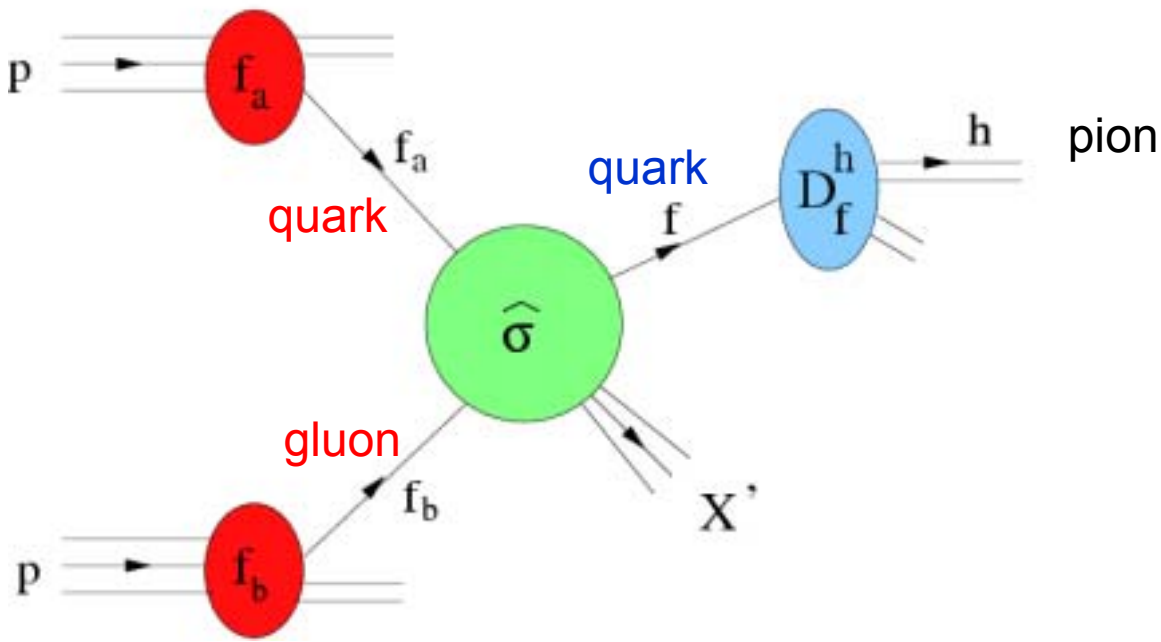
1990s to present: confirmed in "DIS" fixed target experiments using electrons and muons to probe the spin structure of the proton

2001 to present: **probe the spin structure of the proton using quarks and gluons *(strongly interacting probes see both the gluons and quarks in the proton):* RHIC**

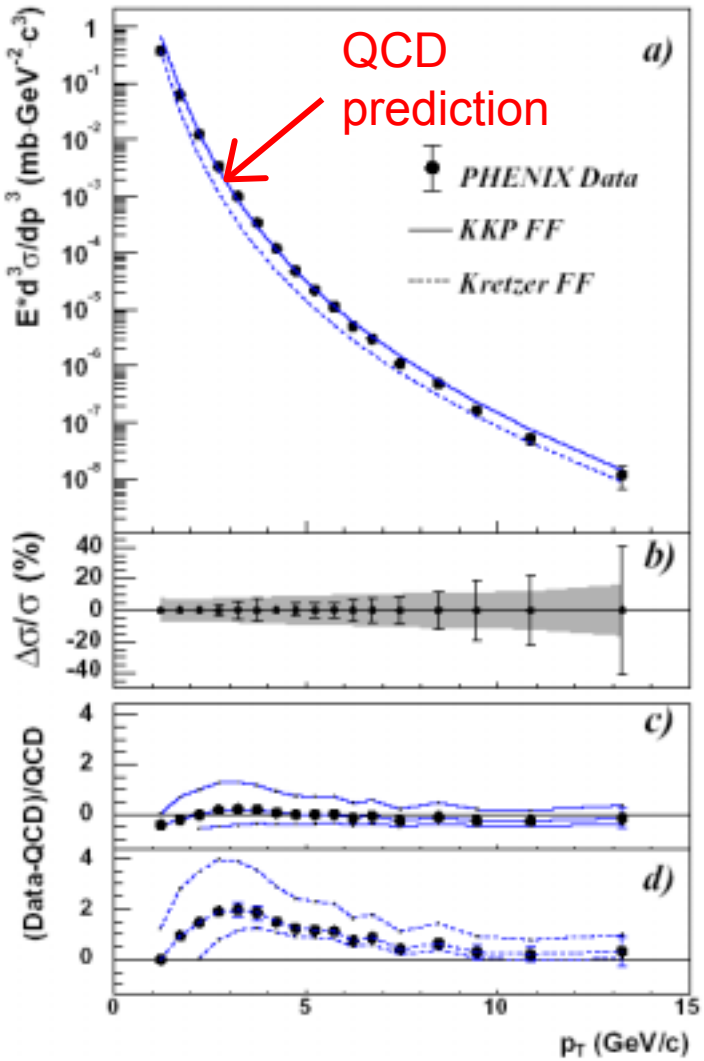
Measuring the proton spin structure…

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

Quarks contribute only 20%!

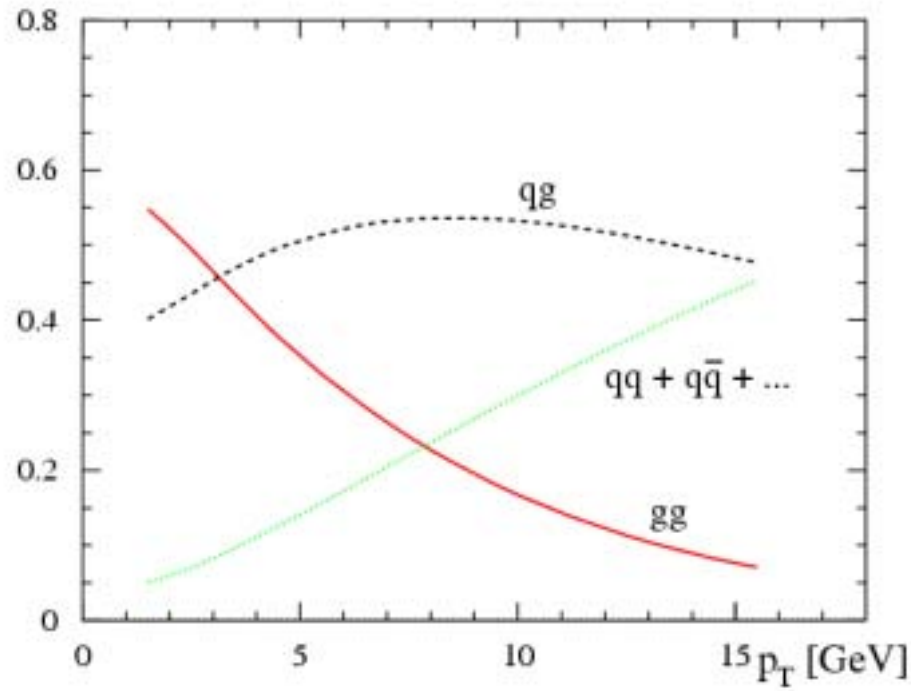


Cornerstones to the RHIC Spin program



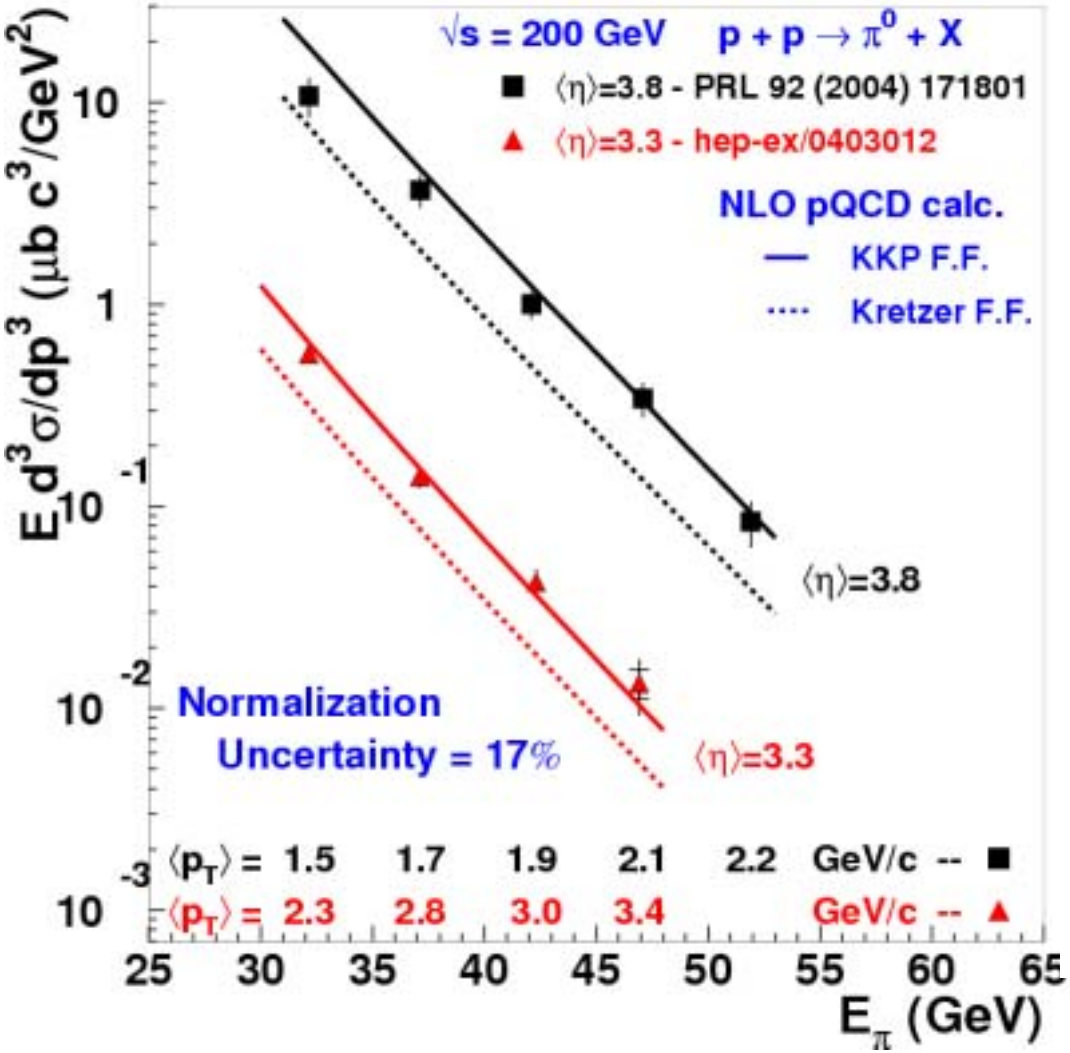
$$pp \rightarrow \pi^0 X$$

Mid-rapidity: PHENIX



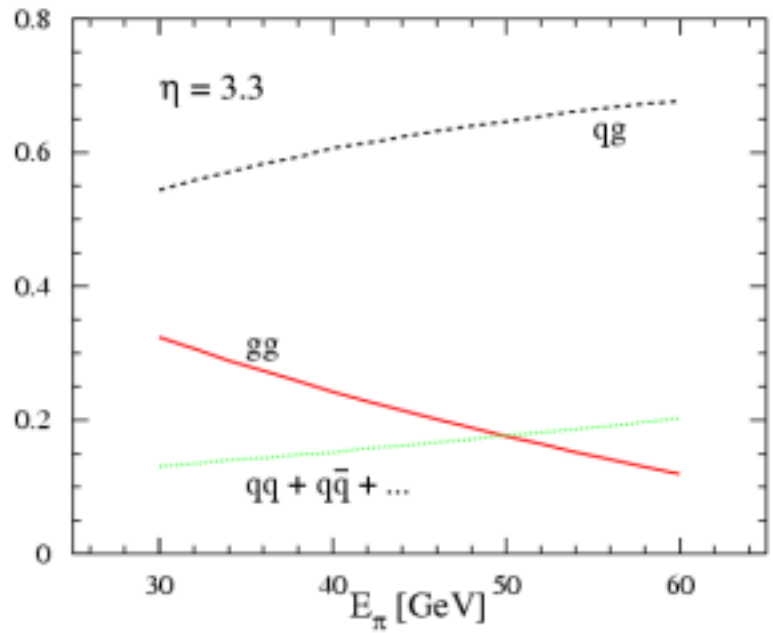
Physical Review Letters **91**, 241803 (2003)

Cornerstones (continued)



$$pp \rightarrow \pi^0 X$$

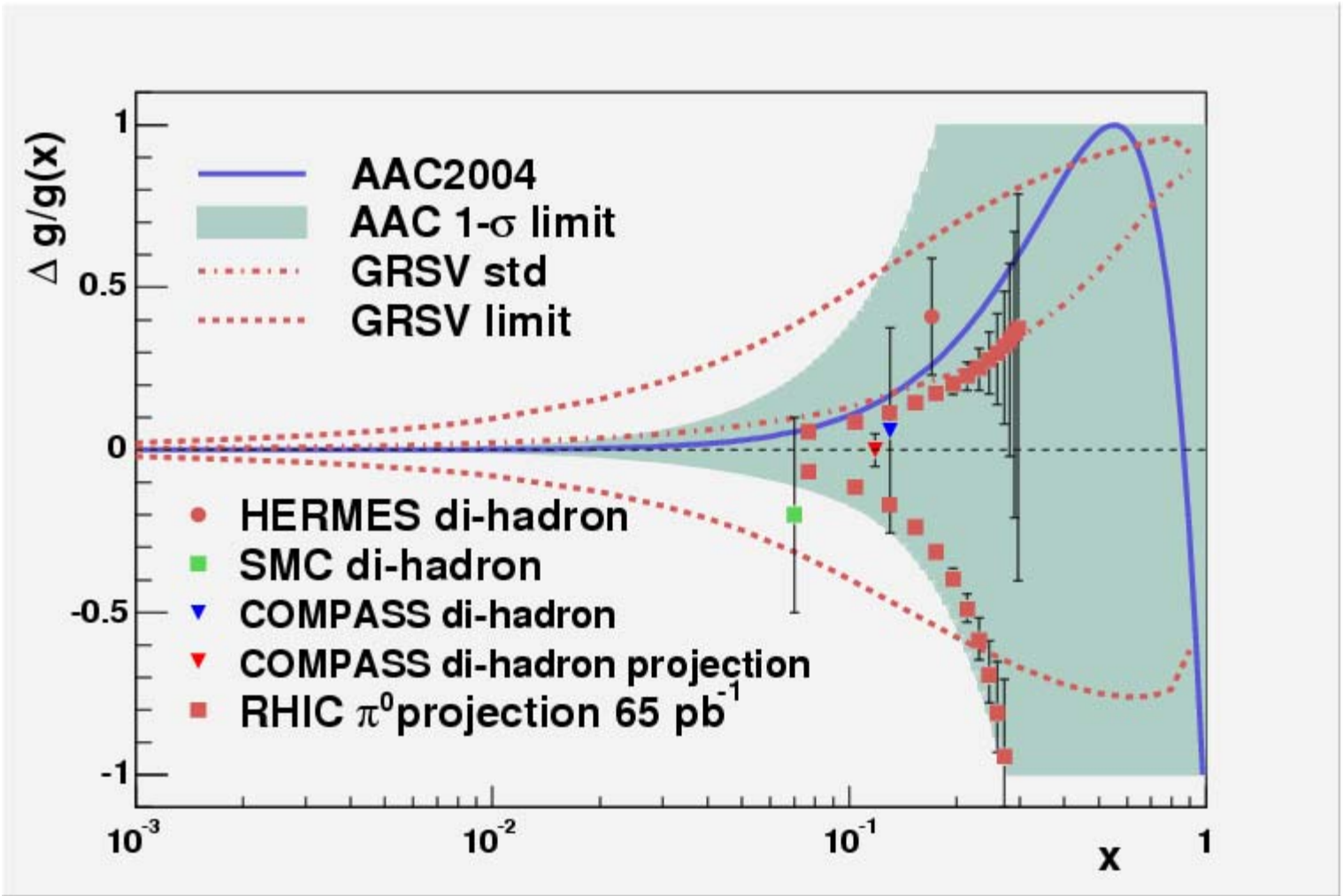
Forward rapidity: STAR



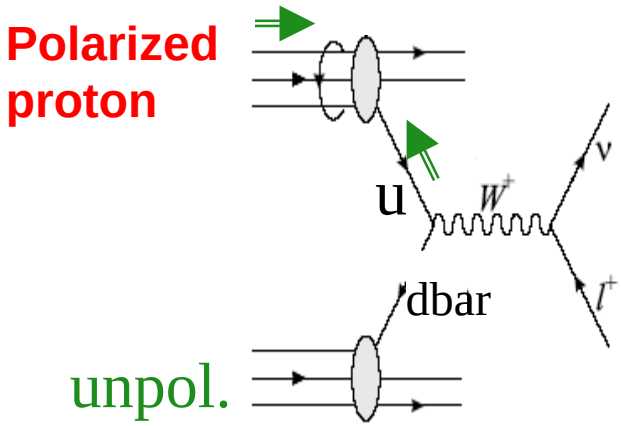
RHIC Spin Physics Program

- *Direct measurement* of polarized gluon distribution *using multiple probes*
- Direct measurement of *anti-quark polarization* using parity violating production of $W^{+/-}$
- Transverse spin: Transversity & transverse spin effects: possible connections to orbital angular momentum?

Gluon Polarization Sensitivity Of RHIC Spin

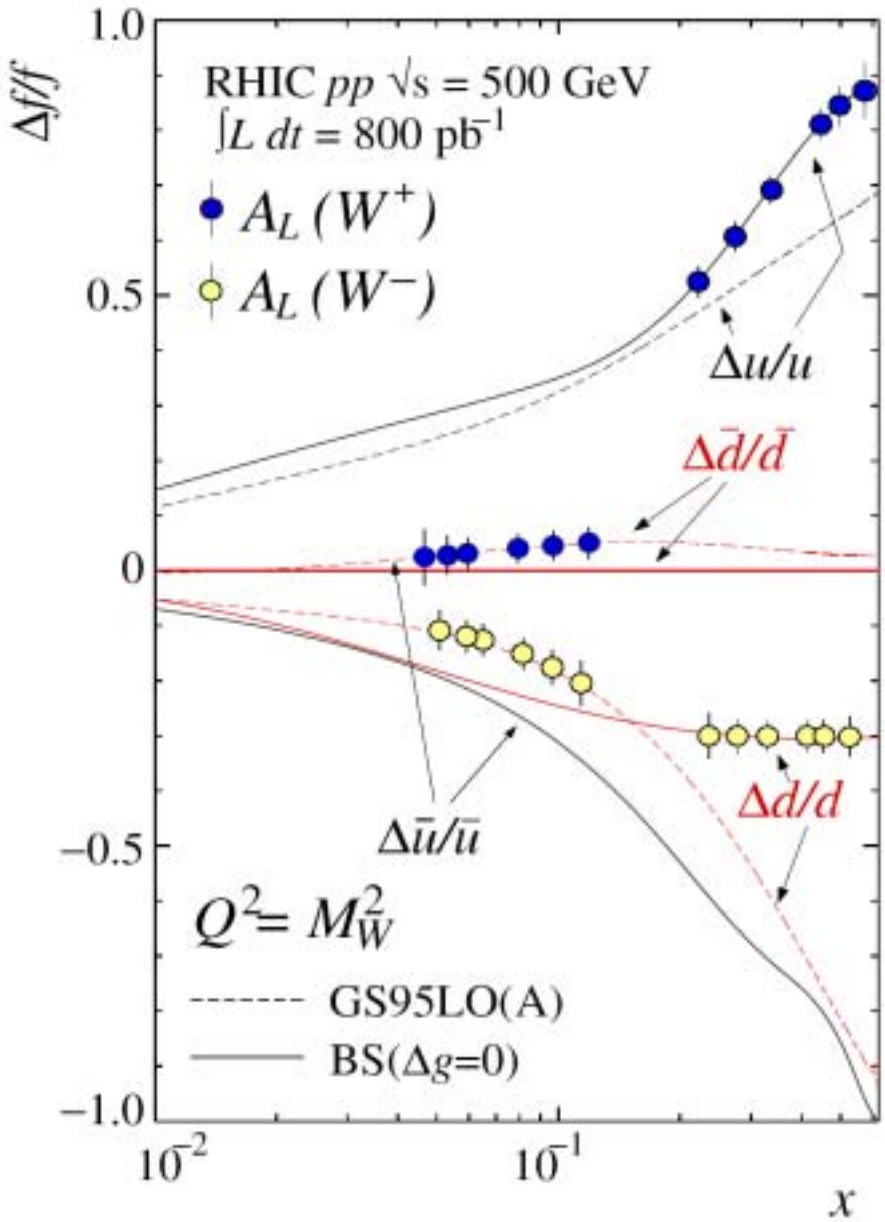


Δq-$\Delta\bar{q}$ at RHIC via W production



$$\Delta d + \bar{u} \rightarrow W^-$$
$$\Delta \bar{u} + d \rightarrow W^-$$
$$\Delta \bar{d} + u \rightarrow W^+$$
$$\Delta u + \bar{d} \rightarrow W^+$$

$$\mathbf{A_L} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

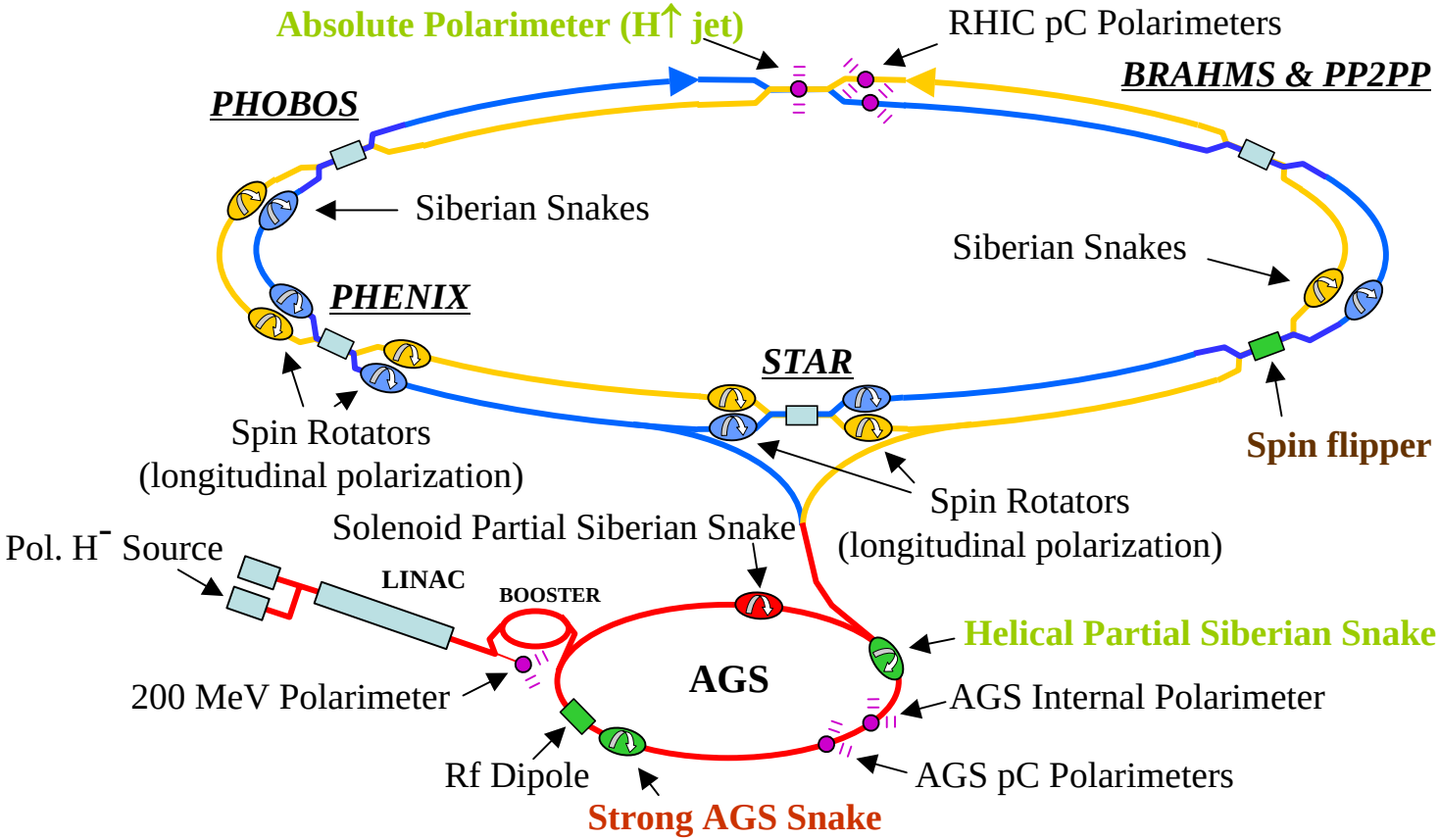


PHENIX & STAR Upgrades required; Begin data 2009

Accomplishments

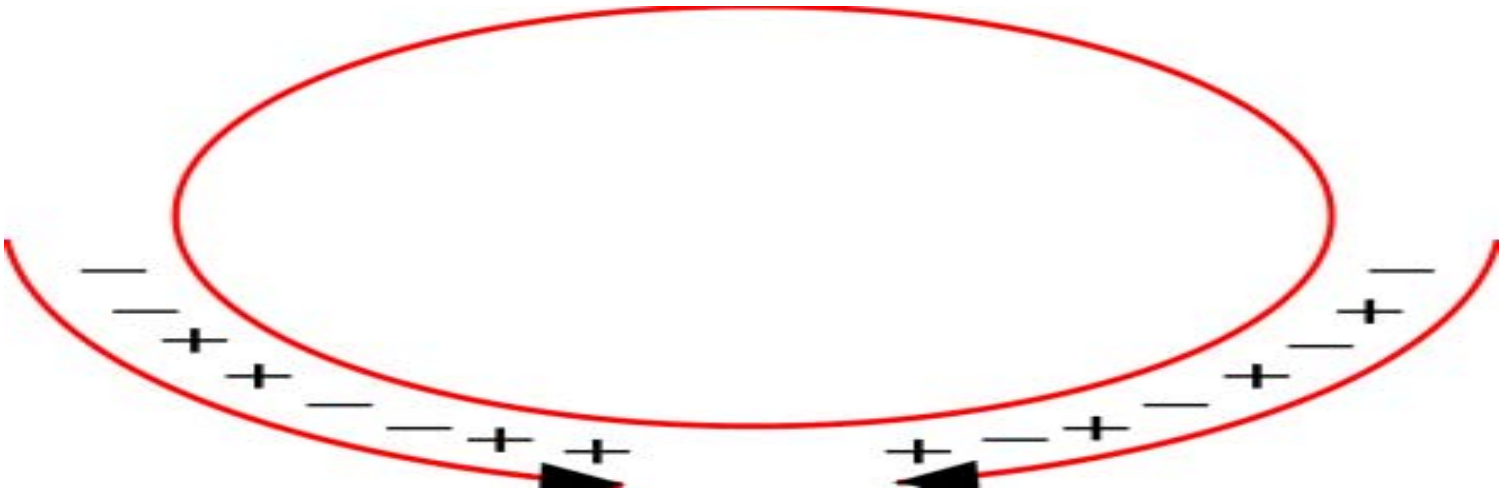
- 2003 Data Analysis:
  - ---transverse asymmetry forward and backward pi0
    - ---PRL on 2002 data result
  - ---direct photon cross section
  - ---PRL for pi0 helicity asymmetry
  - ---observe suppression of forward pi0s and 2-particle correlations in d-Au collisions
- 2004 Run:
  - ---helicity asymmetry mid-rapidity pi0
  - ---polarized atomic hydrogen jet in RHIC
- 2005 Run:
  - ---50% polarization
  - ---factor 70 improvement in figure of merit
  - ---observed neutron asymmetry for root(s)=410 GeV

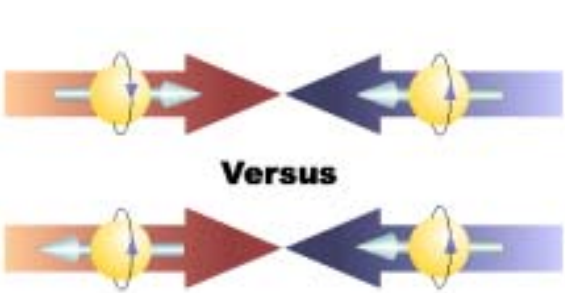
RHIC Polarized Collider

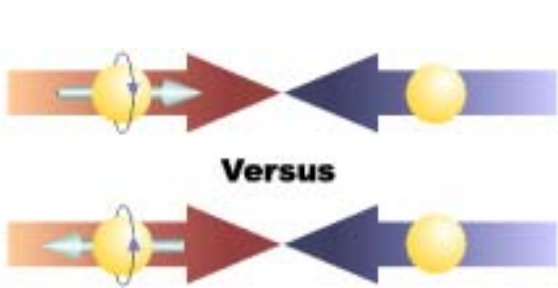


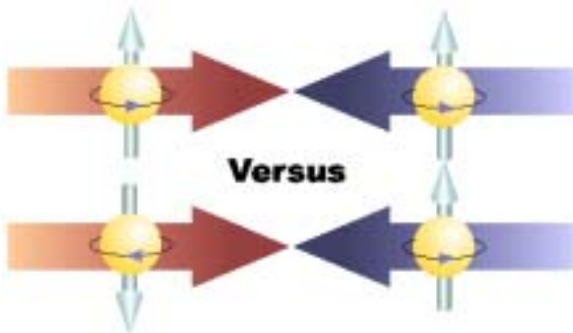
- Installed and commissioned during FY04 run
- Plan to be commissioned during FY05 run
- Installed and plan to be commissioned during FY05 run

Exquisite Control of Systematics

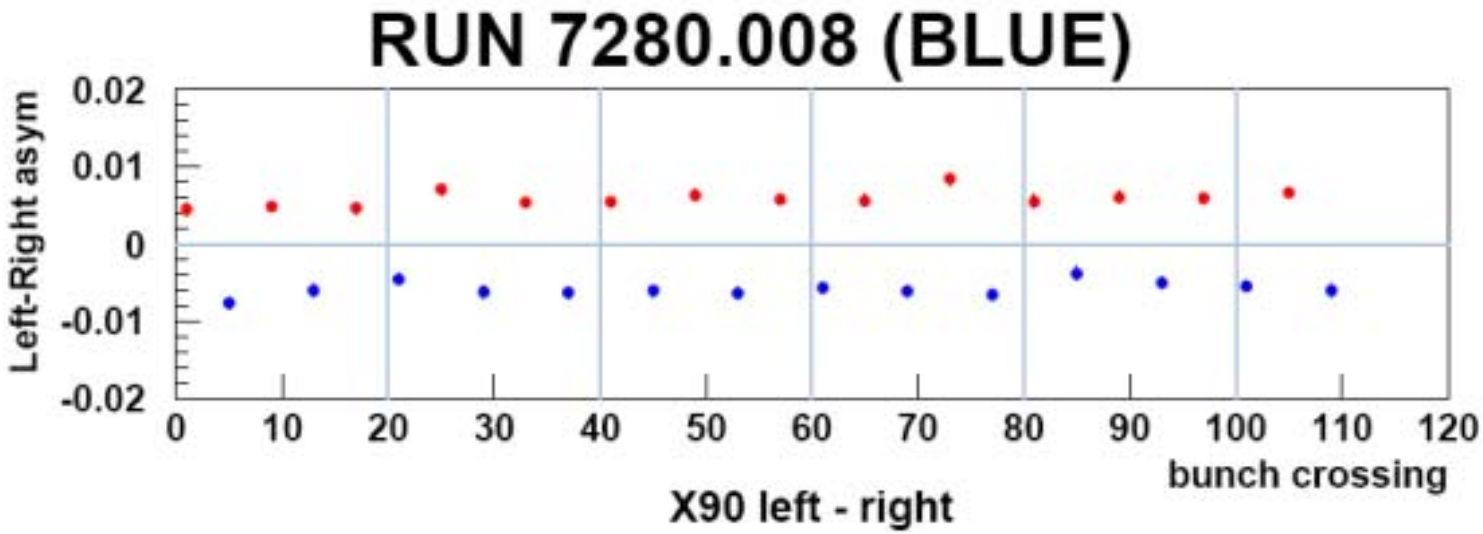






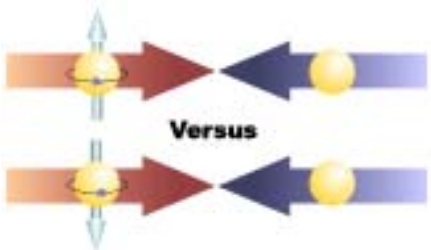


Raw asymmetries from carbon polarimeter by bunch (2005)



Spin Asymmetries

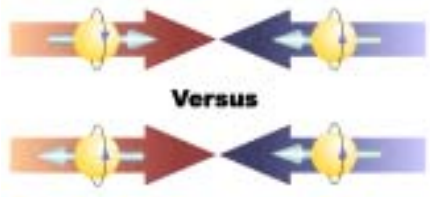
Single Spin Asymmetries



Physics Asymmetries

$$A_N = \frac{1}{P_B}\left(\frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\downarrow}\right)$$

Double Spin Asymmetries



$$A_{LL} = \frac{1}{P_B{}^2}\left(\frac{N_{\uparrow\uparrow} - N_{\uparrow\downarrow}}{N_{\uparrow\uparrow} + N_{\uparrow\downarrow}}\right) \Rightarrow \boxed{\Delta G}$$

measurements

Caveats:

- **-RHIC CNI Absolute polarization still preliminary.**
- **-Result Averaged over azimuthal acceptance of detectors.**
- **-Positive XF (small angle scattering of the polarized proton).**

Run 2 Published Result.

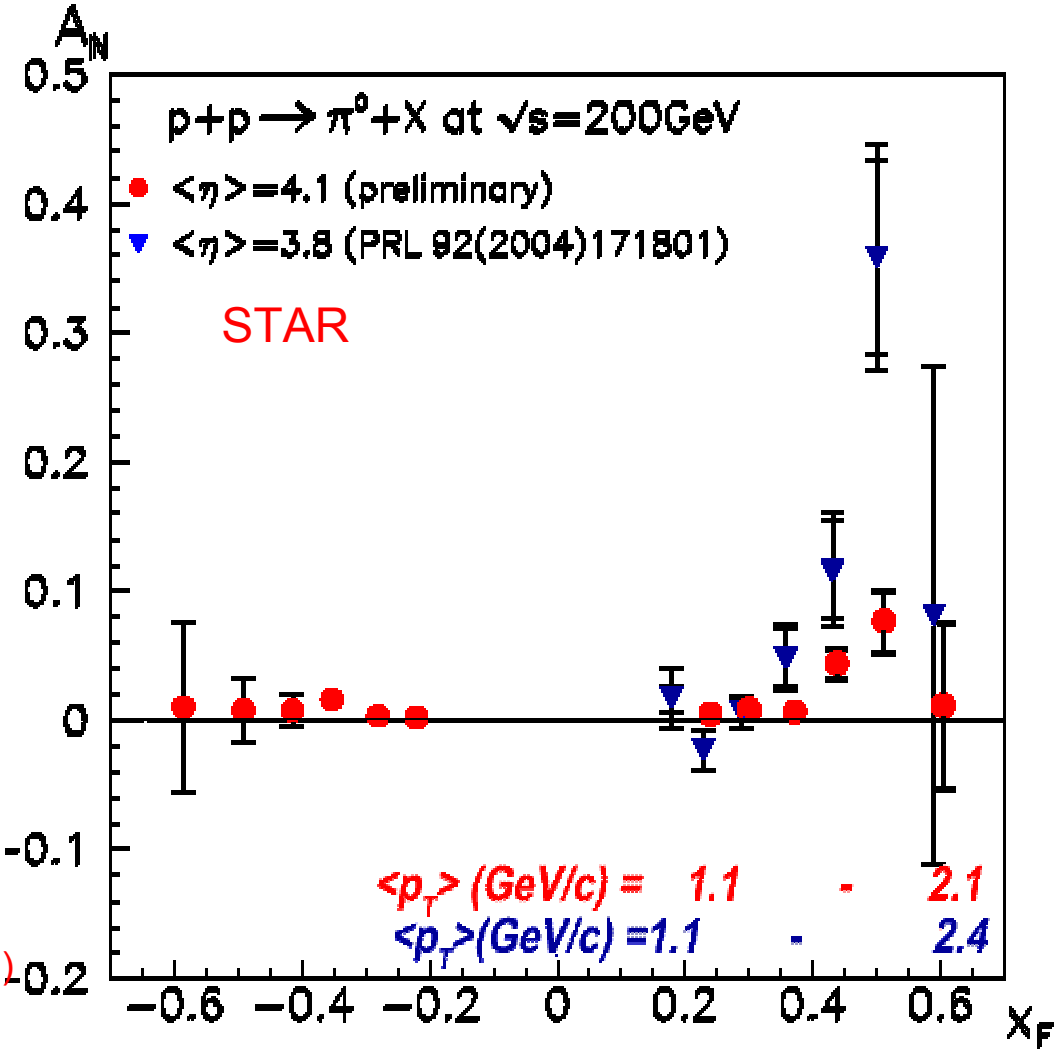
Run 3 Preliminary Result.

- **-More Forward angles.**
- **-FPD Detectors.**
- **- ~0.25 pb^{-1} with P_{beam}~27%**

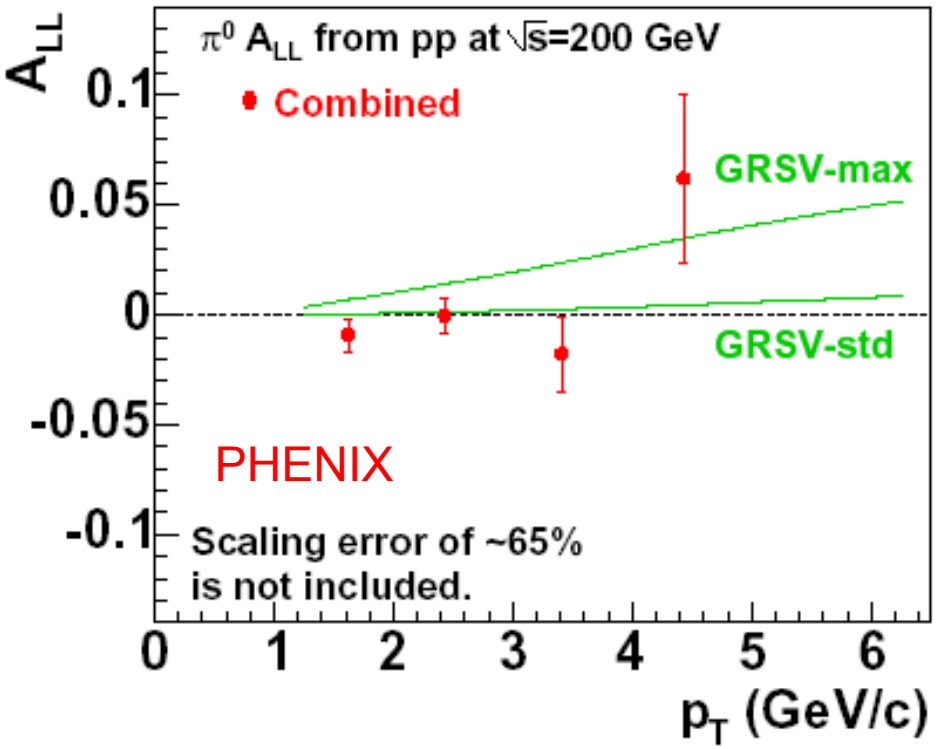
Run 3 Preliminary Backward Angle Data.

- **-No significant Asymmetry seen.**

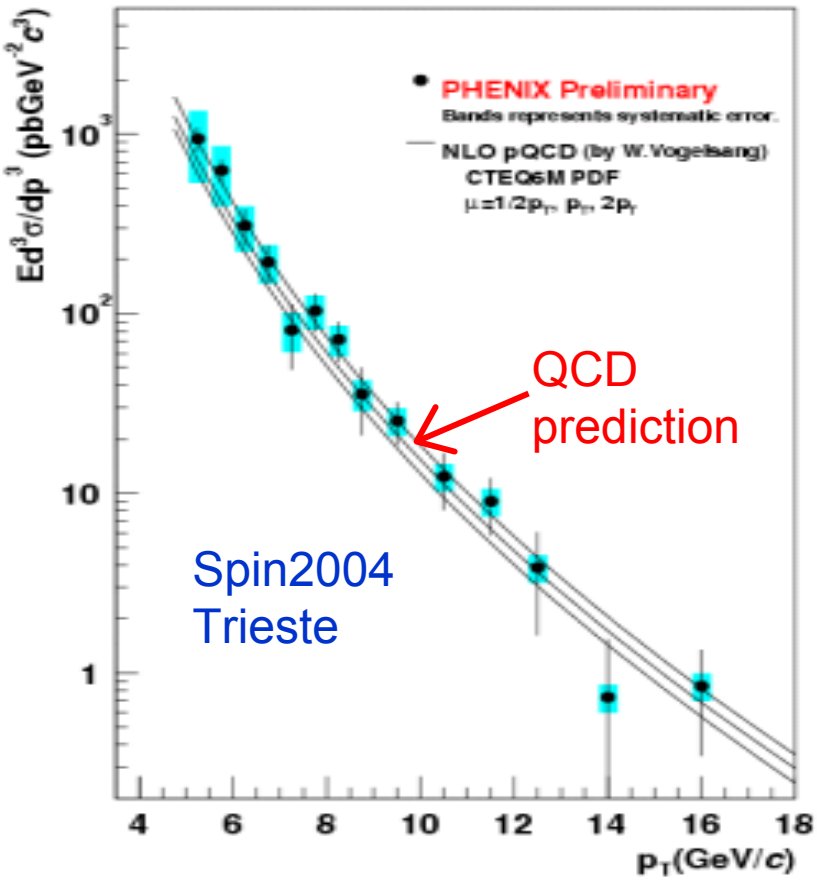
(Presented at Spin 2004: hep-ex/0502040)



2004: Gluon polarization and Direct γ



pp → γ X

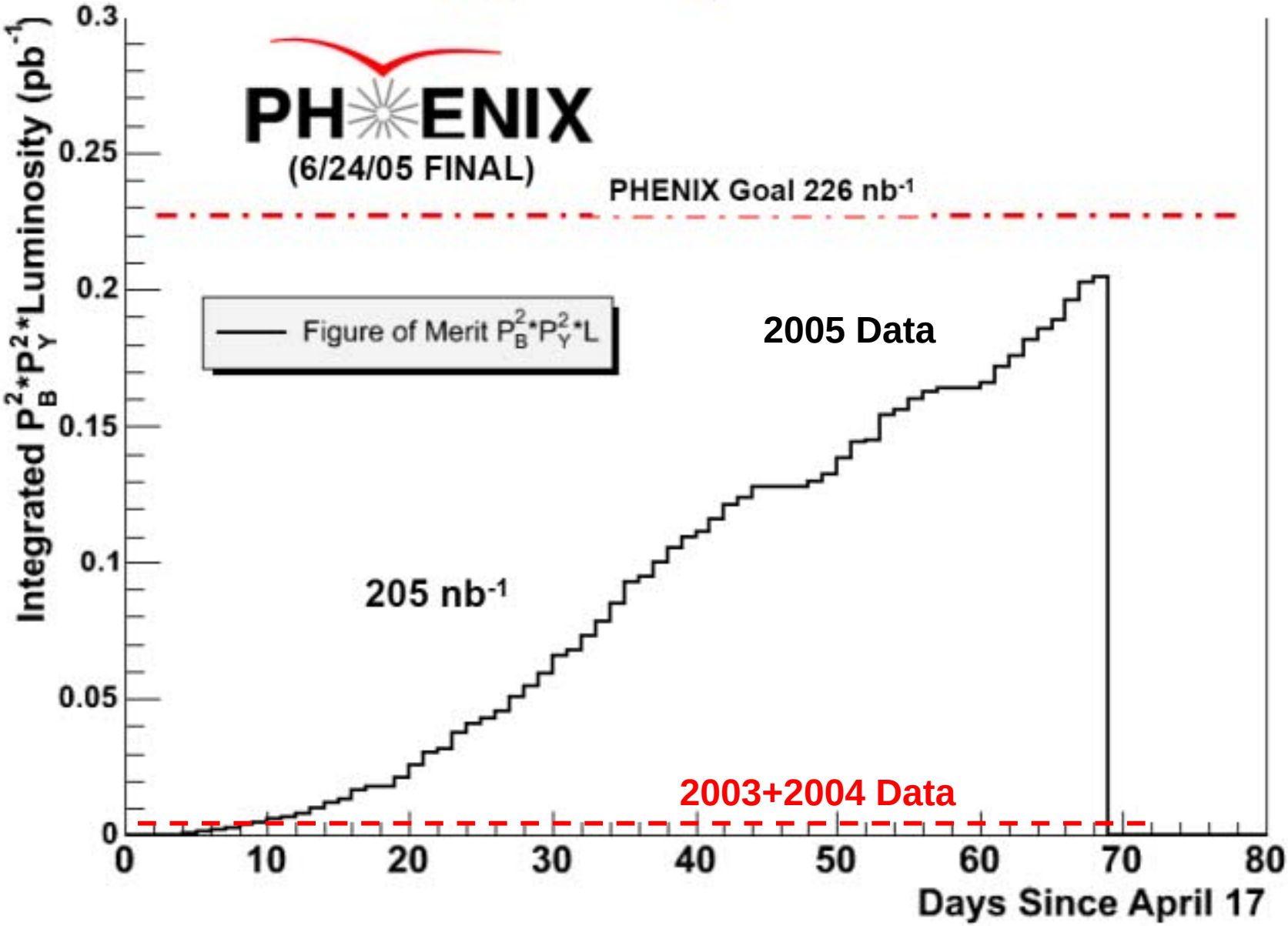


Spin2004, Trieste:

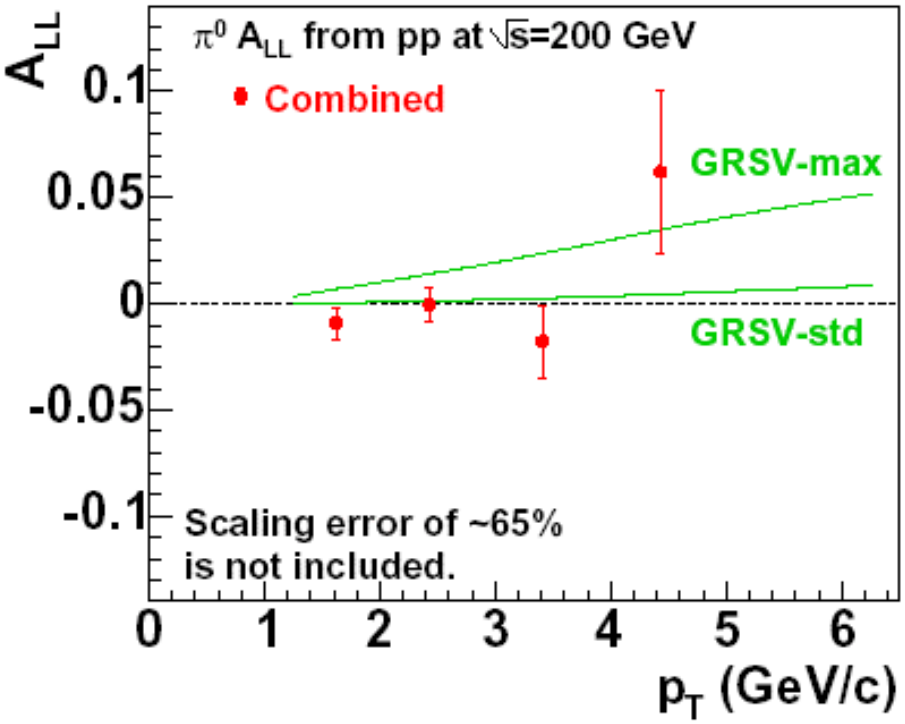
2003: Phys. Rev. Lett. **93**, 202002 (1994) and 2004 data combined

...also a cornerstone of the RHIC Spin program

200 GeV pp "Figure of Merit"

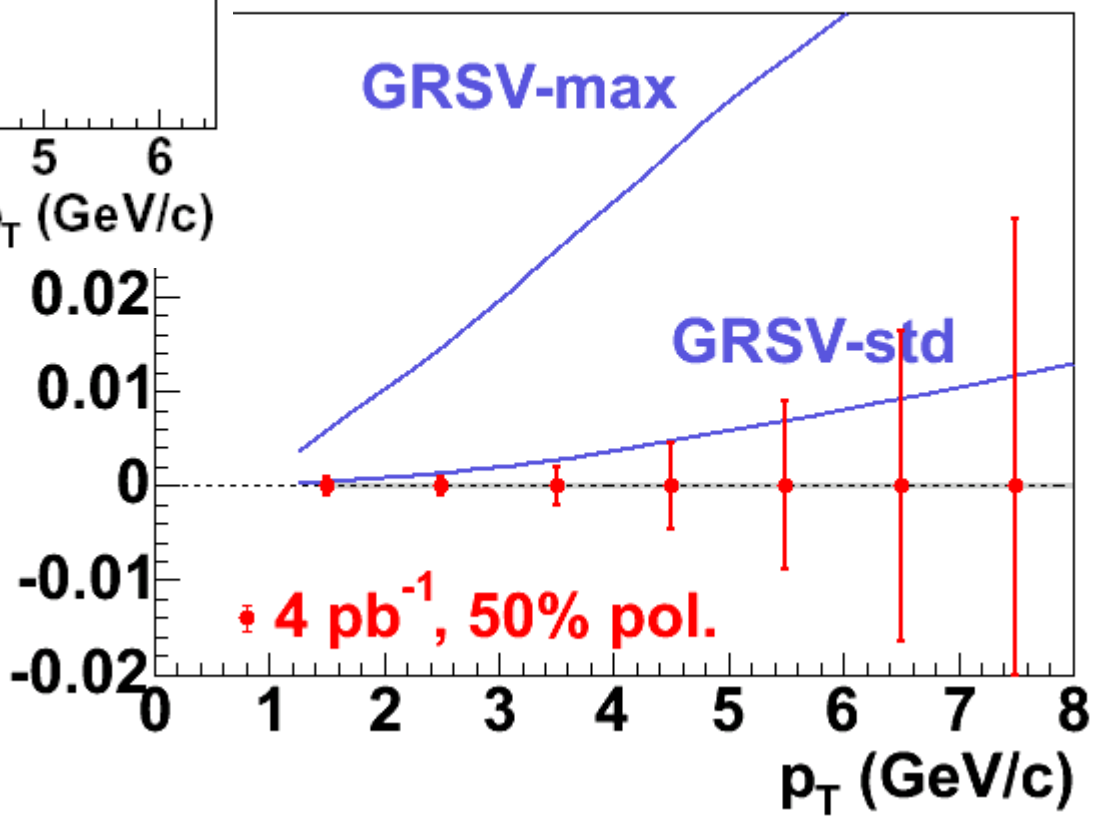


2003+2004 Data

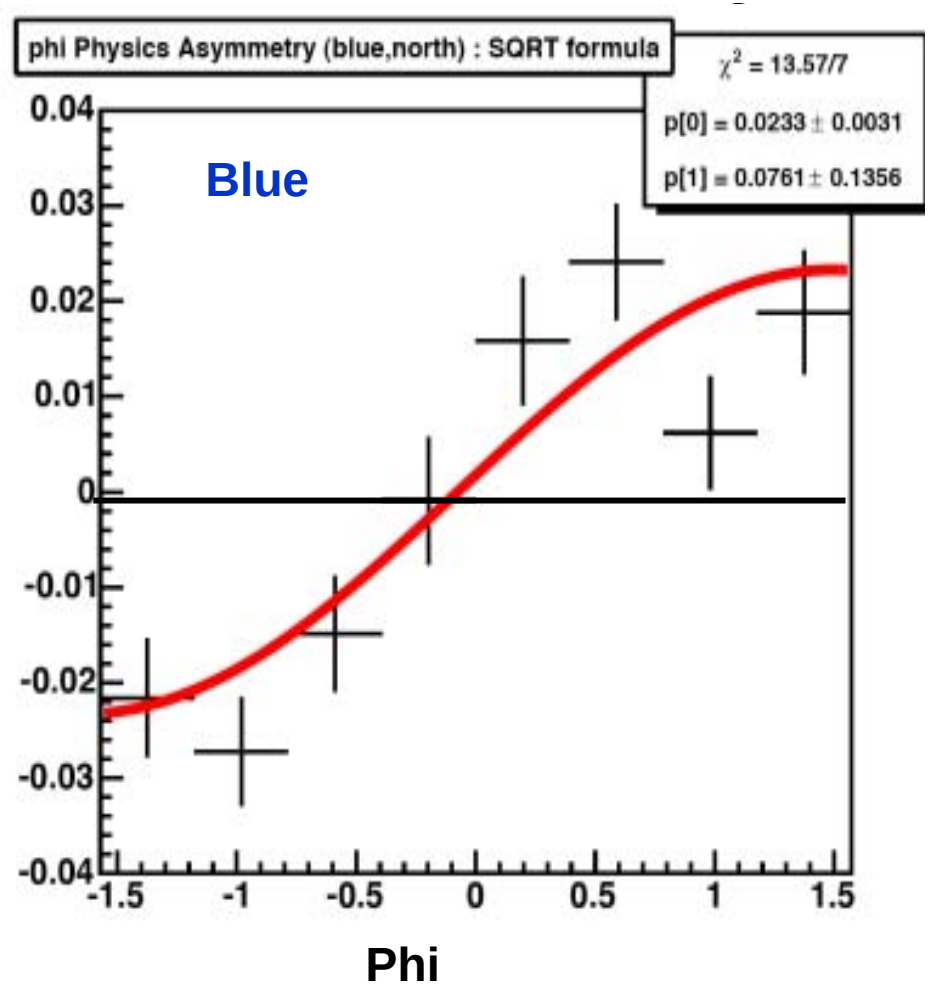


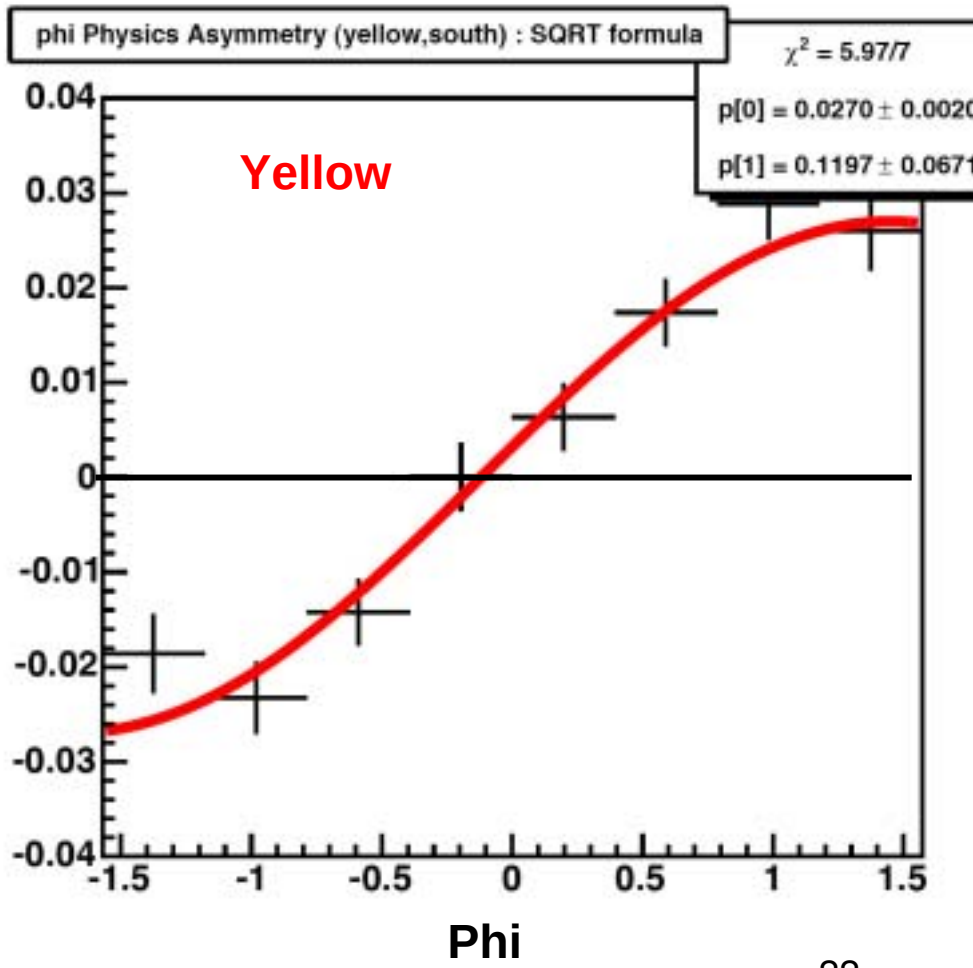
Projected 2005 Sensitivity

PHENIX



410 GeV pp running: Forward neutron asymmetry





Polarimetry

1. Provide polarization measurements for accelerator.
2. Provide polarization measurements for experiments.

I. Alekseev, A. Bravar, G. Bunce, S. Dhawan, R. Gill, W. Haeberli, H. Huang, G. Igo, O. Jinnouchi, K. Kurita, Y. Makdisi, A. Nass, H. Okada, N. Saito, H. Spinka, E. Stephenson, D. Svirida, D. Underwood, C. Whitten, T. Wise, J. Wood, A. Zelinski

The Road to Precision Polarimetry

1. **Polarized atomic hydrogen jet target with precisely measured polarization**

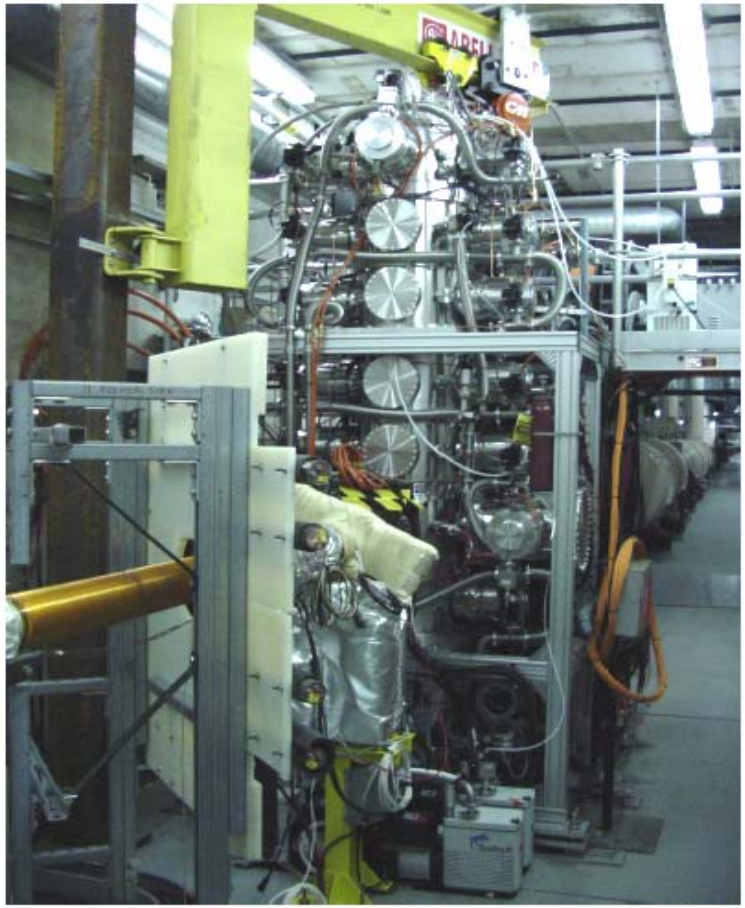
2. **Elastic scattering of beam from target, flipping beam polarization vs. flipping target polarization**

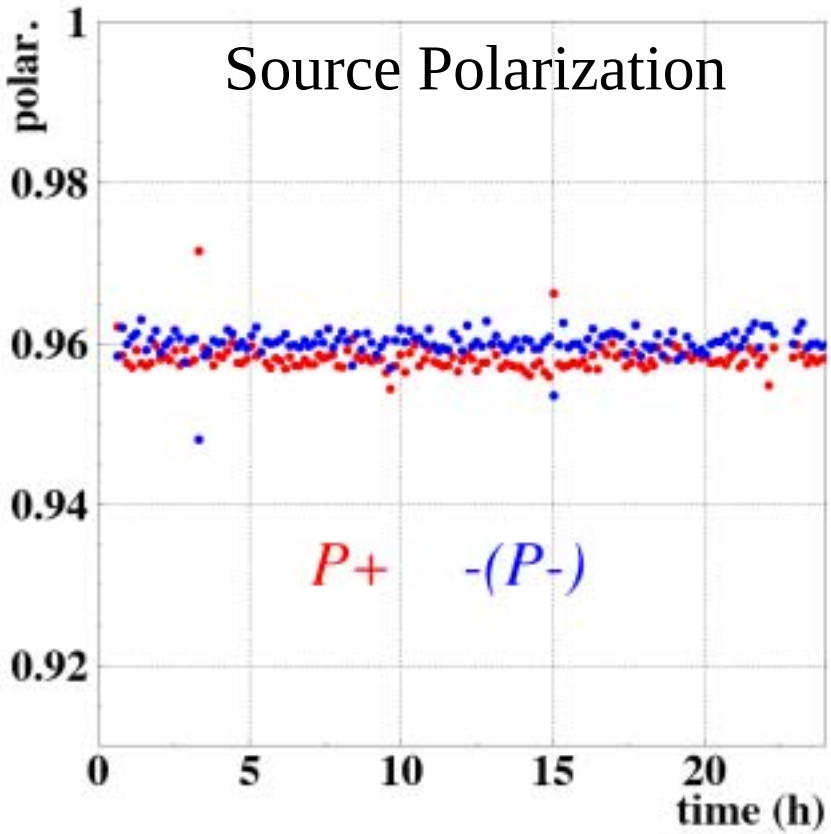
3. **Elastic scattering of beam from carbon target, calibrate carbon analyzing power**

4. **Measure asymmetry for elastic scattering from carbon, known analyzing power: Pbeam for each measurement**

$$\frac{\Delta P_{beam}}{P_{beam}} = \left(\frac{\Delta P_{target}}{P_{target}}\right) \oplus \left(\frac{\Delta \varepsilon}{\varepsilon}\right)_{pp} \oplus \left(\frac{\Delta A_N}{A_N}\right)_{pC} \oplus \left(\frac{\Delta \varepsilon}{\varepsilon}\right)_{pC} \leq 6\%$$

2004: RHIC Polarized Atomic H Jet

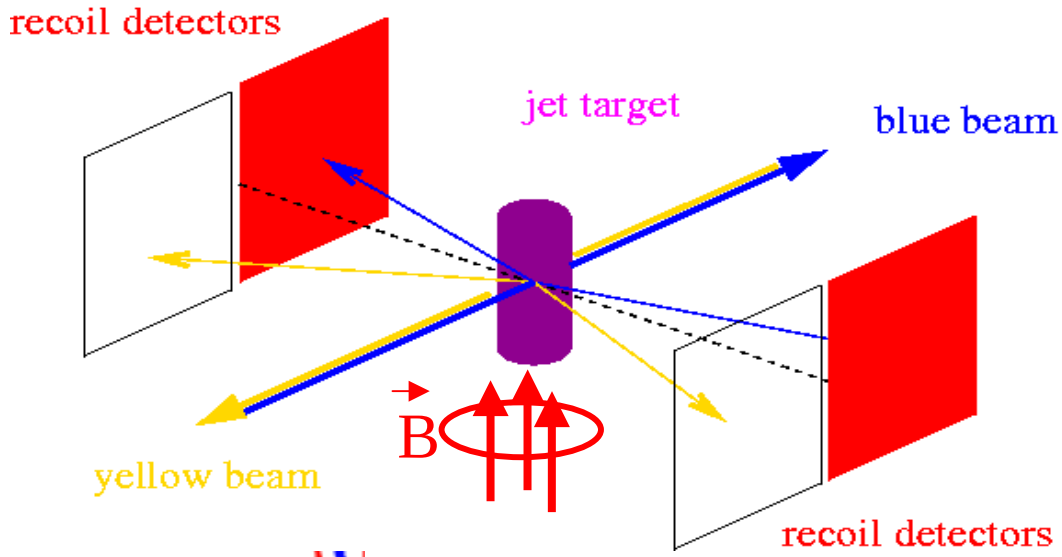


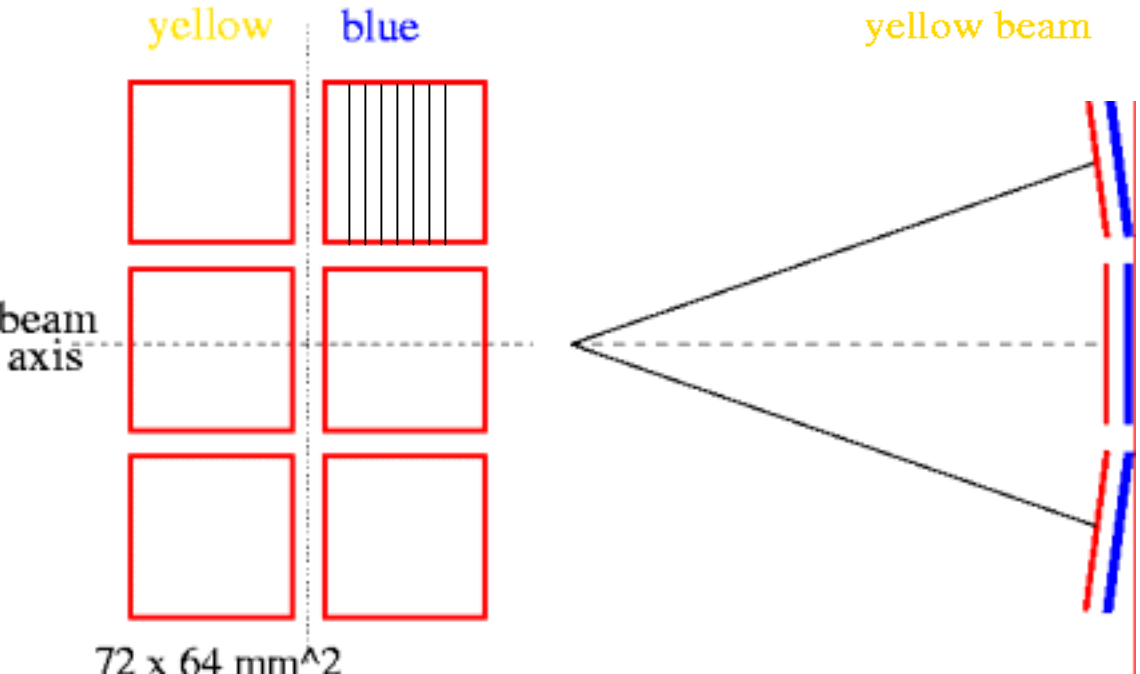


$$P_{Beam} = P_{Jet} \times \frac{\epsilon_{Beam}}{\epsilon_{Jet}} \text{ where } \epsilon = \frac{N_{up} - N_{down}}{N_{up} + N_{down}}$$

Recoil Si spectrometer

6 Si detectors covering
the blue beam =>
MEASURE
energy (res. < 50 keV)
time of flight (res. < 2 ns)
scattering angle (res. ~ 5 mrad)
of recoil protons from
pp → *pp* elastic scattering

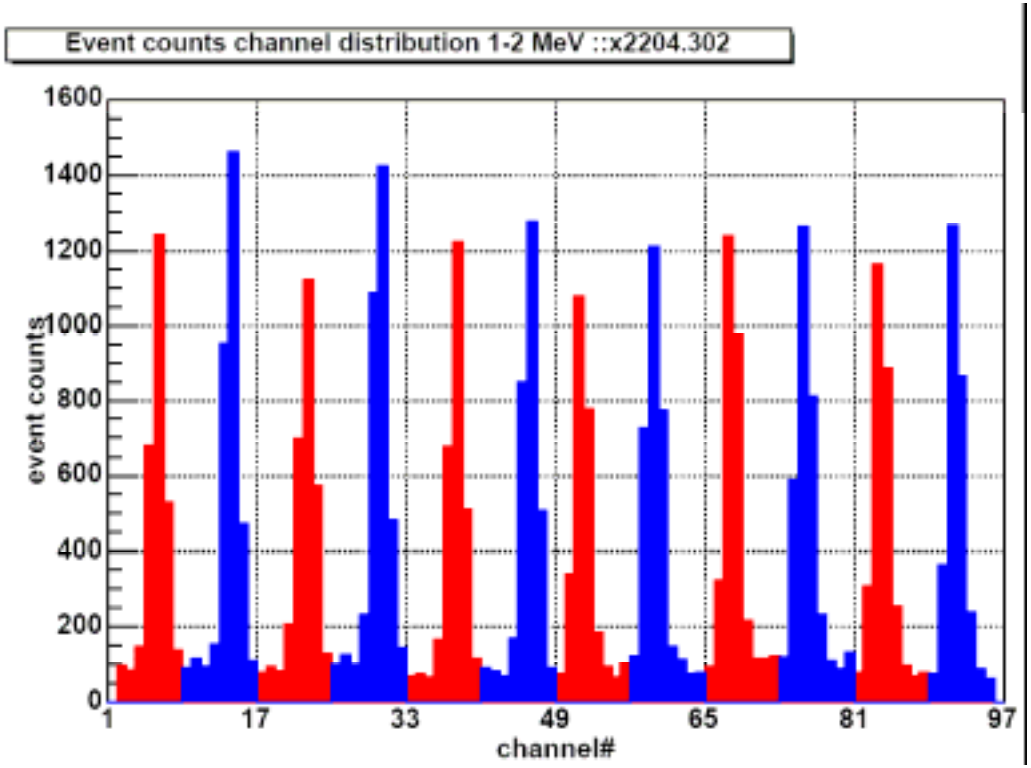


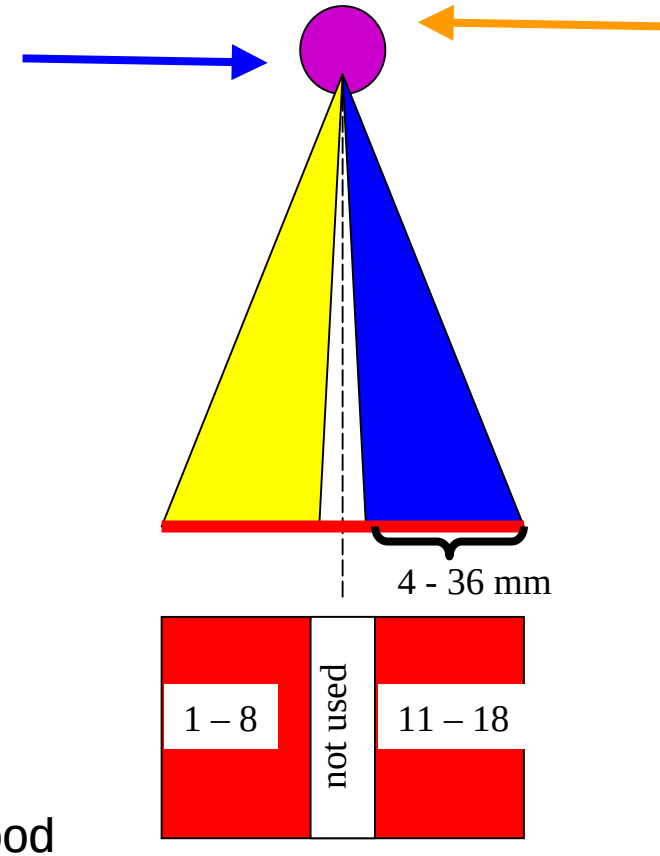


HAVE "design"
azimuthal coverage

one Si layer only
⇒ smaller energy range
⇒ reduced bkg rejection power

JET: Elastic pp Events





Backgrounds 2 x larger than in 2004; not fully understood
In principle could run with both beams at the same time, however decided to run with one beam at the time

Statistics: (04/20 – 06/07)
1,500 k events in Yellow
900 k events in Blue
10 % empty target runs (background studies)
1 – 2 MeV region

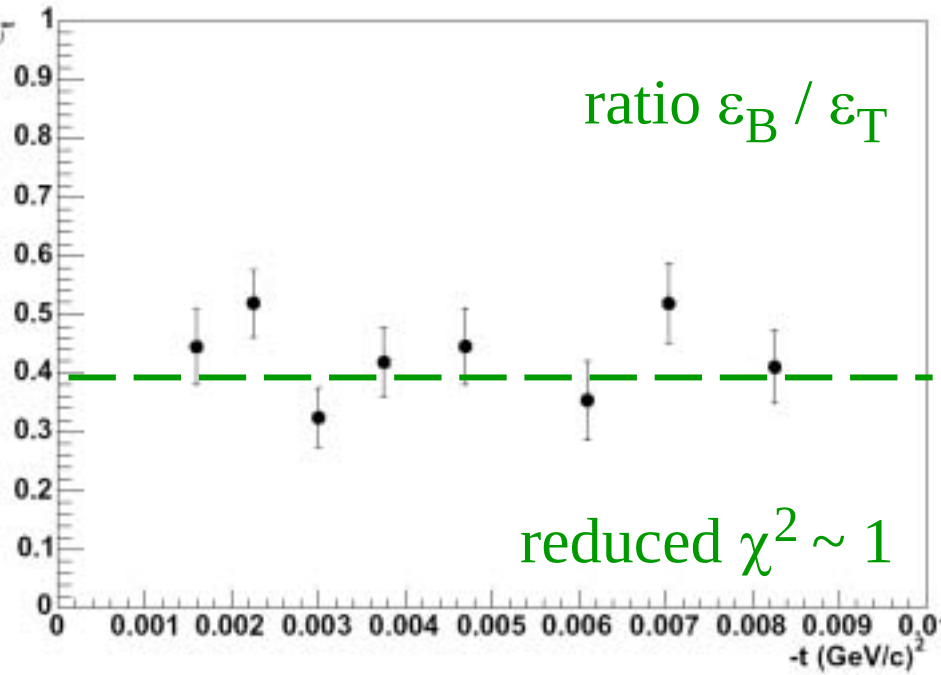
"self calibrating"

"Target": ε_T – target asymmetry average over beam polarization

"Beam": ε_B – beam asymmetry average over target polarization

$$P_{Beam} = P_{Target} \cdot \frac{\varepsilon_{Beam}}{\varepsilon_{Target}}$$

P_B



2004:

tot sys = 0.016

$P_{BEAM} = 0.392 \pm 0.021\ (stat) \pm 0.008\ (\Delta P_{TARGET}) \pm 0.014\ (sys)$

$= 0.392 \pm 0.026$ **2004 ERROR: $\Delta P_{BEAM} / P_{BEAM} = 6.6\ \%$**

$\langle P_{Beam} \rangle$ during the 2005 run ~ 0.5 (~10% error, mainly from backgrounds)

Summary for Polarimetry

- the polarimeters work reliably
- steady progress in understanding and addressing systematic issues
- fast measurements of P_{beam} in few min. (AGS) / 10 sec. (RHIC)
- polarized gas JET target works beautifully

  (target, recoil spectrometer, …)
- During 2004 run with Jet target precision on beam polarization

  $\Delta P_{BEAM} / P_{BEAM} = 6.6\ \%$
- based on present understanding and developments in 2005 expect

  ~ <10 % “calibration” of *pC* polarimeters

Plans

- **Longitudinal spin**

  ---gluon polarization at root(s)=200 GeV to 2009

  ---W parity violating production: anti-quark polarizations by flavor

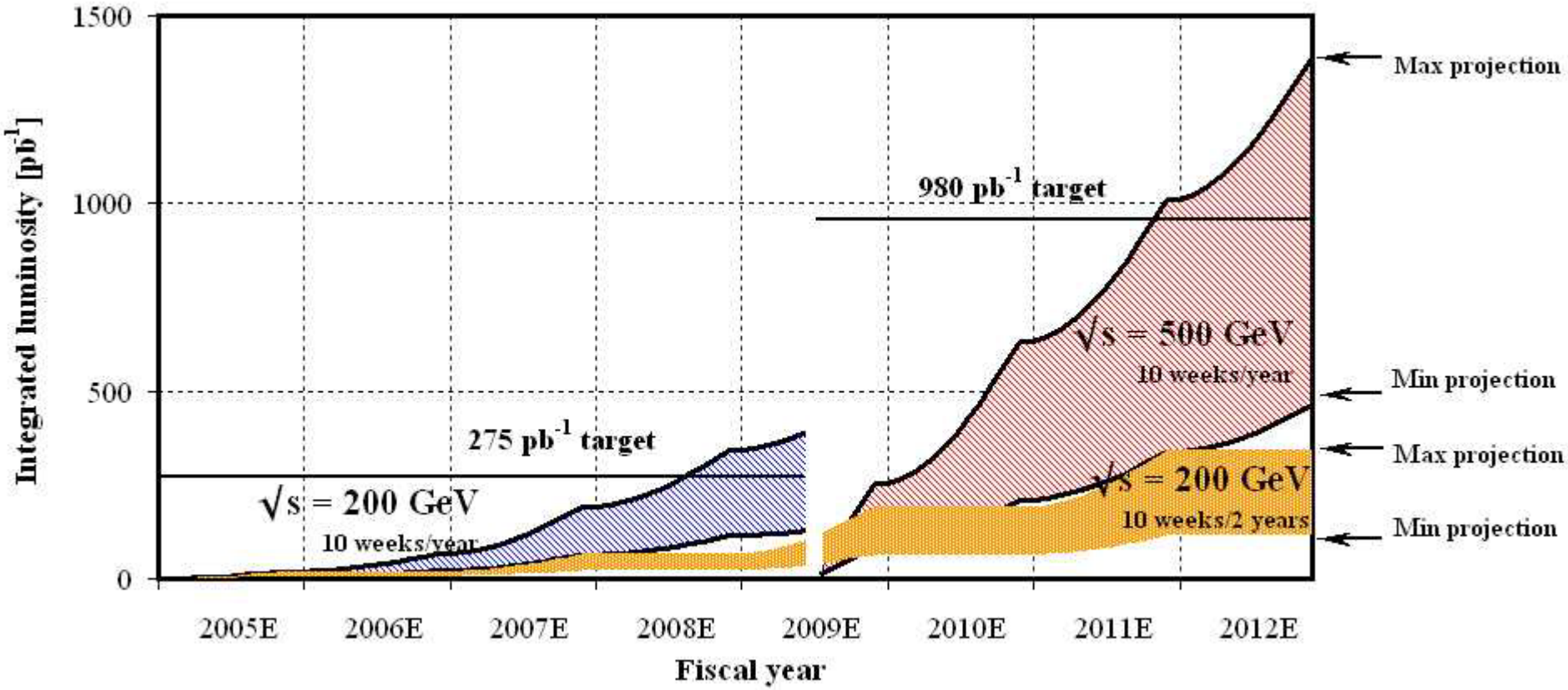
  ---2009-2012, 500 GeV

- **Transverse spin**

  ---study quark transversity, quark analyzing power, orbital angular momentum of quarks and gluons in proton

- **Probe gluon density at low x**

RHIC Spin Plan: Luminosity Projections



Issues

- Excellent support for spin running
  ---extended running in 2003, 2004
  ---spectacular spin run in 2005
- Future RHIC running (discussed in spin plan)
- Support for new initiatives: transverse spin
- Support for BNL Spin Group stalled
  ---build STAR group!
- Long term plan for polarimetry

Transverse Spin

The RHIC (STAR) results at forward rapidity demonstrated that large spin effects exist in the perturbative QCD regime.

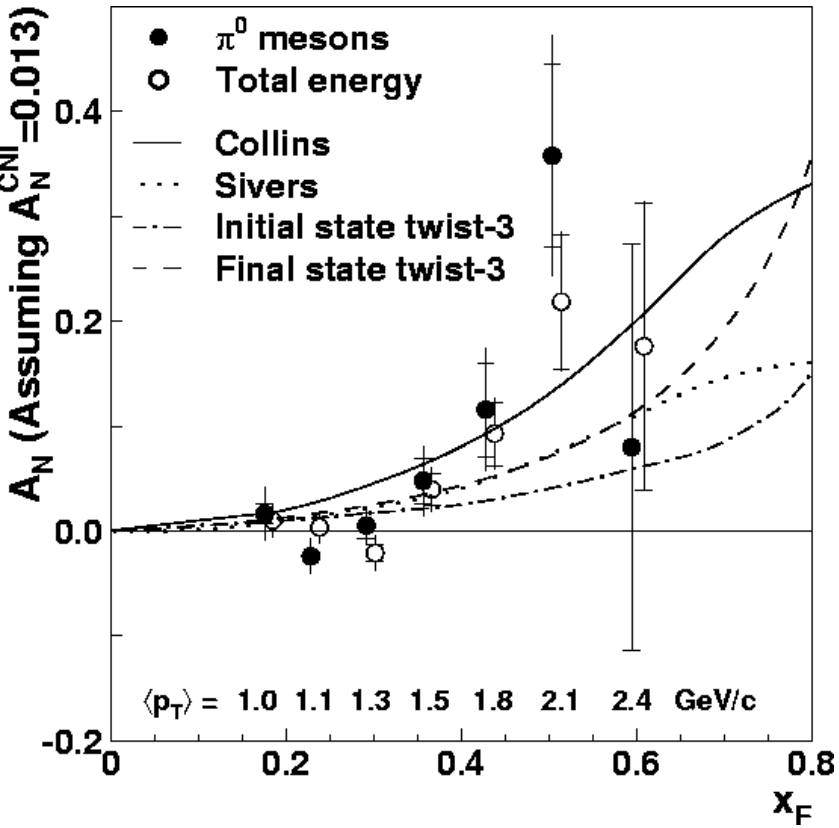
There are new results from Belle showing large fragmentation asymmetry for polarized quarks.

New HERMES results show large asymmetries for orbital angular momentum effects in polarized proton.

First A_N Measurement at STAR

prototype FPD results

STAR collaboration
Phys. Rev. Lett. **92** (2004) 171801



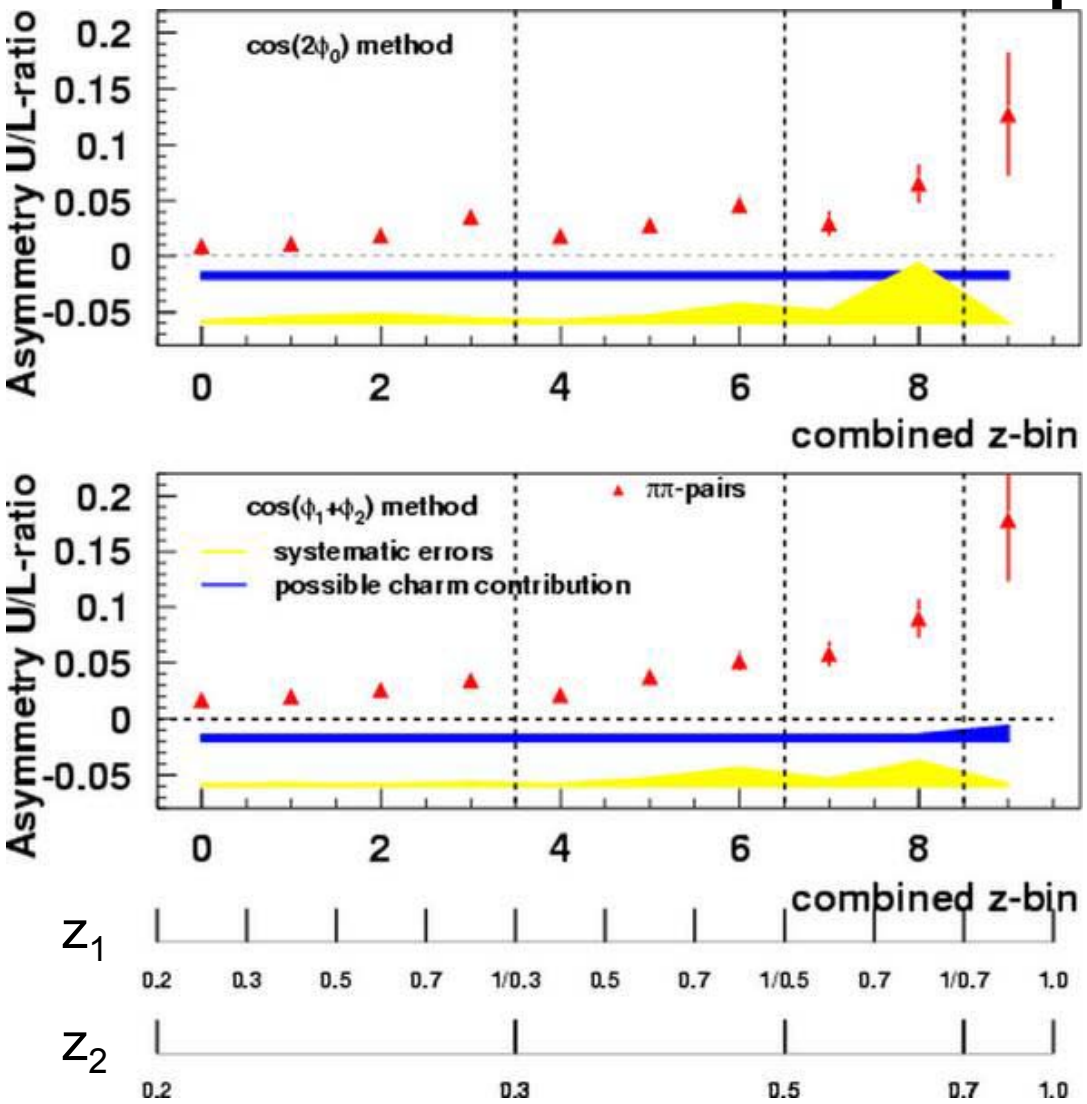
√s=200 GeV, <η> = 3.8

Similar to result from E704 experiment (√s=20 GeV, $0.5 < p_T < 2.0$ GeV/c)

Can be described by several models available as predictions:

- Sivers: spin and $k_\perp$ correlation in parton distribution functions (initial state)
- Collins: spin and $k_\perp$ correlation in fragmentation function (final state)
- Qiu and Sterman (initial state) / Koike (final state): twist-3 pQCD calculations, multi-parton correlations

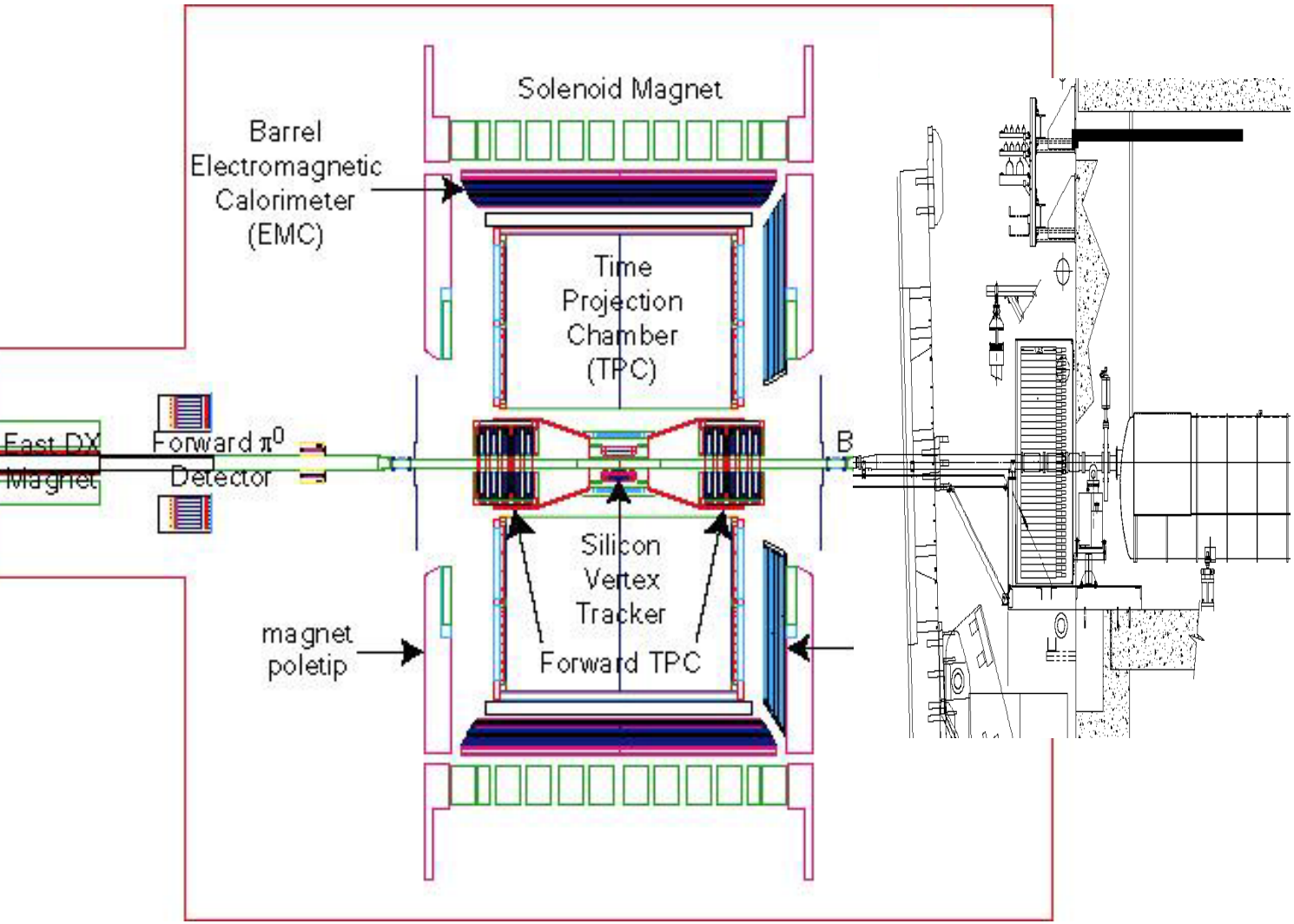
Belle Results for π-pairs for 30fb^{-1}



Ralf Seidl (RBRC) at DIS05, Madison, Wisc. April 05

Quark fragmentation has very large analyzing power!

STAR detector layout with FMS



TPC: -1.0 < η < 1.0

FTPC: 2.8 < |η| < 3.8

BBC : 2.2 < |η| < 5.0

EEMC:1 < η < 2

BEMC:-1 < η < 1

FMS: 2.5<η< 4.0

New FMS Calorimeter
Lead Glass From FNAL E831

Loaded On a Rental Truck for Trip To BNL

Manpower and current support

STAR: Les Bland (tenured) **Group Support: $1700K**
Akio Ogawa (Assoc. Physicist)
Greg Rakness (Res. Associate/Penn State)

PHENIX: Gerry Bunce (Group Leader)
Alexander Bazilevsky (Assoc. Physicist)
+ RBRC (5 Fellows, 2 RAs)

Polarimetry: Sandro Bravar (leads polarimetry; Physicist)
Ron Gill (50% with Physics Dept. safety; continuing)
+ RBRC, Kyoto, CAD, Yale (**WFD contract $122K**)

Pp2pp: Wlodek Guryn (Spokesman; expt. complete; continuing)

Secretary: Melanie Echmalian (50% with Brahms)

Polarimeter Issues

- Develop operations group
- Include experiments for data analysis and evaluation
- Consider developing high density unpolarized hydrogen jet target polarimeter

  ---use analyzing power from polarized jet

  ---precise measurement in few minutes

  ---carbon provides ramp measurements

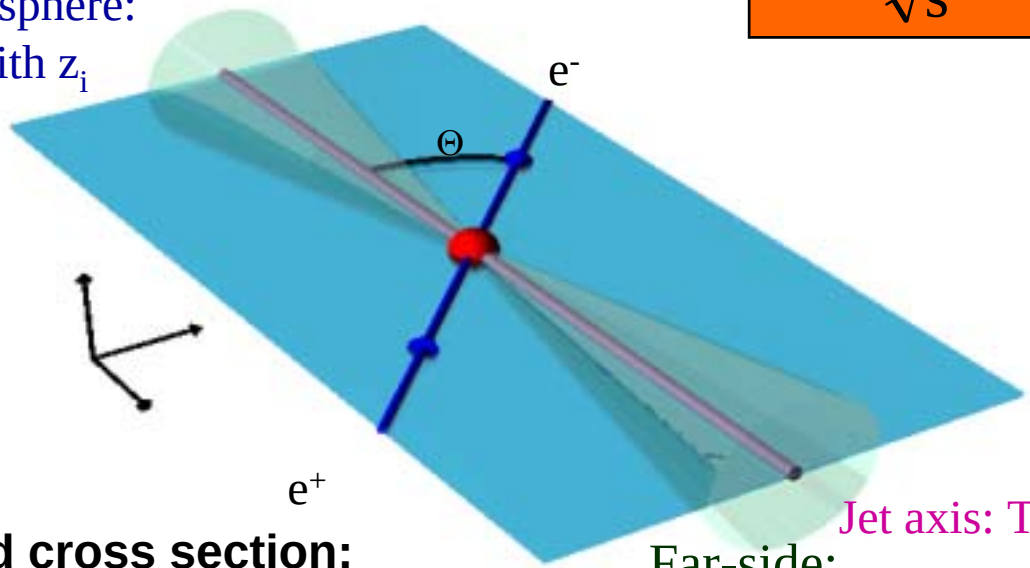
Backup slides

RBRC at Belle: quark analyzing power

e^+e^- CMS frame:

$$z = \frac{2E_h}{\sqrt{s}}, \quad \sqrt{s} = 10.52\,\textbf{GeV}$$

Near-side Hemisphere:
h_i , i=1,N_n with z_i



<$N_{h^+,-}$> = 6.4

Jet axis: Thrust

Far-side:
h_j , j=1,N_f with z_j

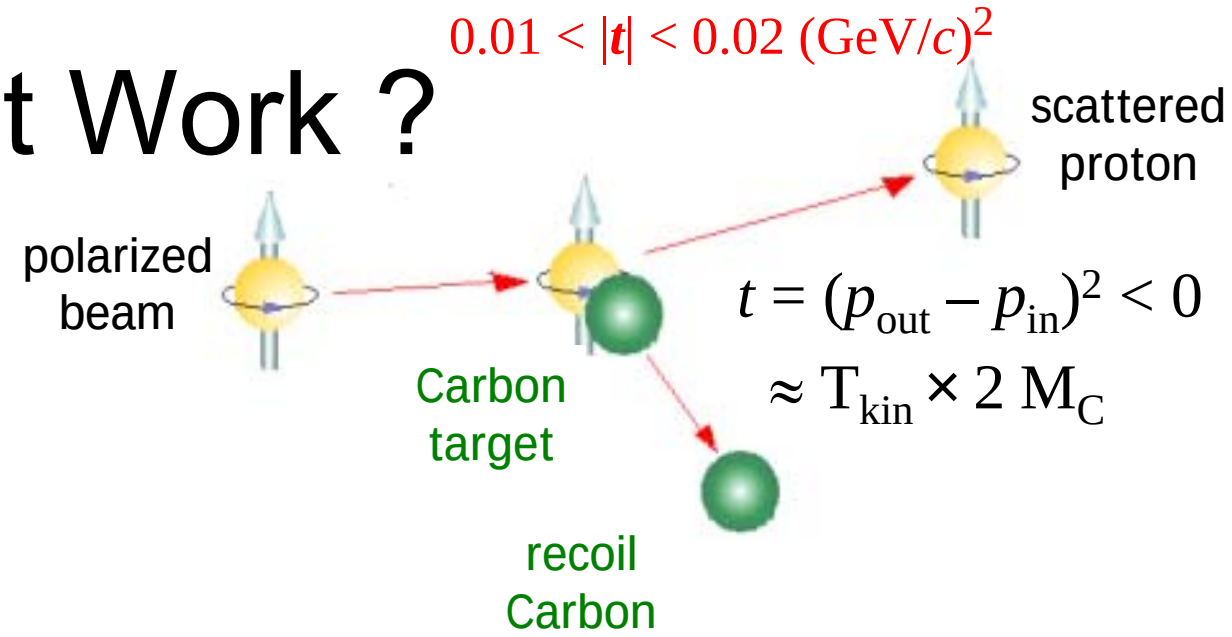
Spin averaged cross section:

$$\frac{d\sigma(e^+e^- \to h_1 h_2 X)}{d\Omega dz_1 dz_2} = \frac{3\alpha^2}{Q^2} A(y) \sum_{a,\bar{a}} e_a^2 D_1(z_1) \overline{D}_1(z_2)$$

$$A(y) = \left(\frac{1}{2} - y + y^2\right) \overset{(cm)}{=} \frac{1}{4}\left(1 + \cos^2\Theta\right)$$

How Does It Work ?

$$P_B = -\frac{1}{A_N} \cdot \frac{N_{left} - N_{right}}{N_{left} + N_{right}}$$



Polarimetry:

requires large F.o.M: A_N^2 ´ *rate* for fast measurement

process with large A_N and not too large (!) σ

(not at any price however, i.e. by increasing the rates)

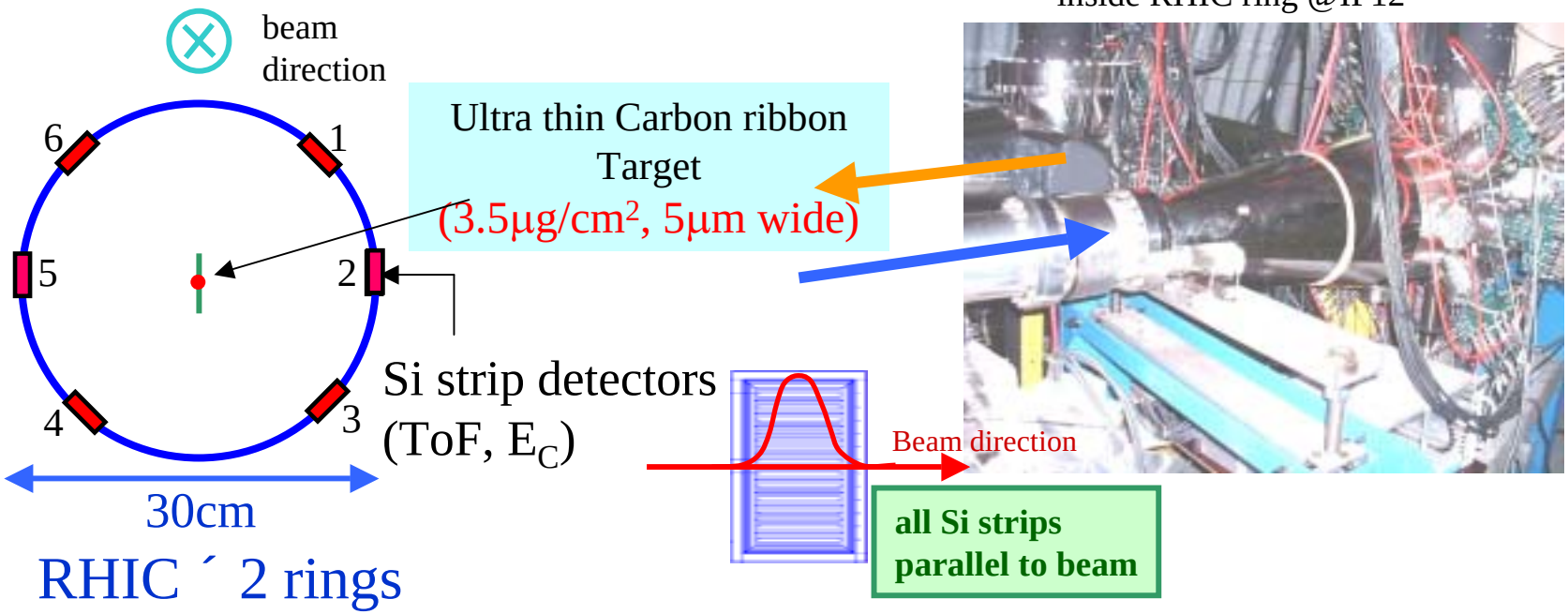
elastic *pC* scattering in the CNI region:

small A_N ~ 1 % (far from ideal !)

⇒ requires large statistics > 10^7, for Δ P_B ~ few %

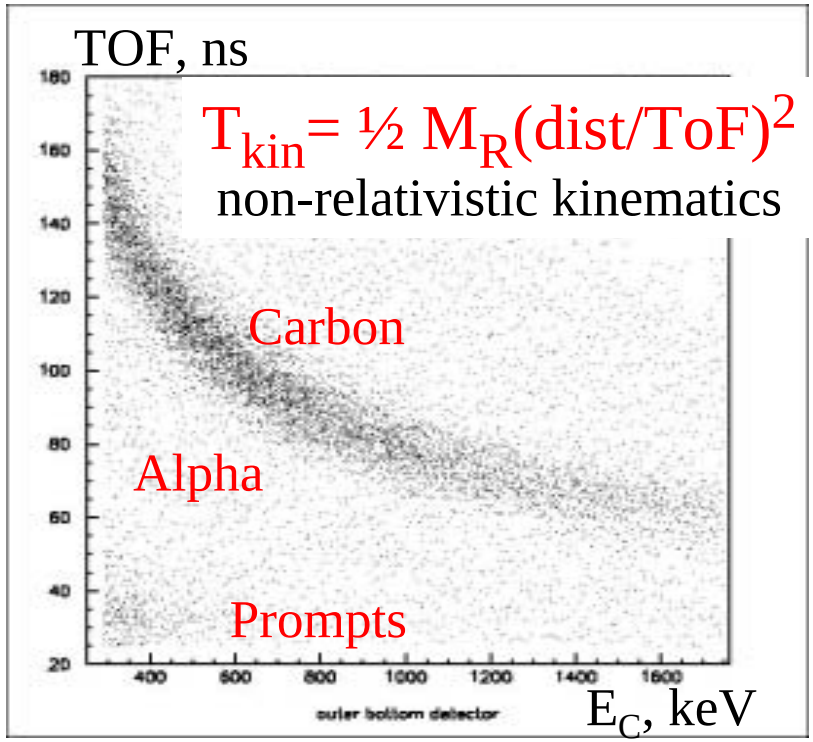
´–section large for *pC* ⇒ measurement takes < 10 sec

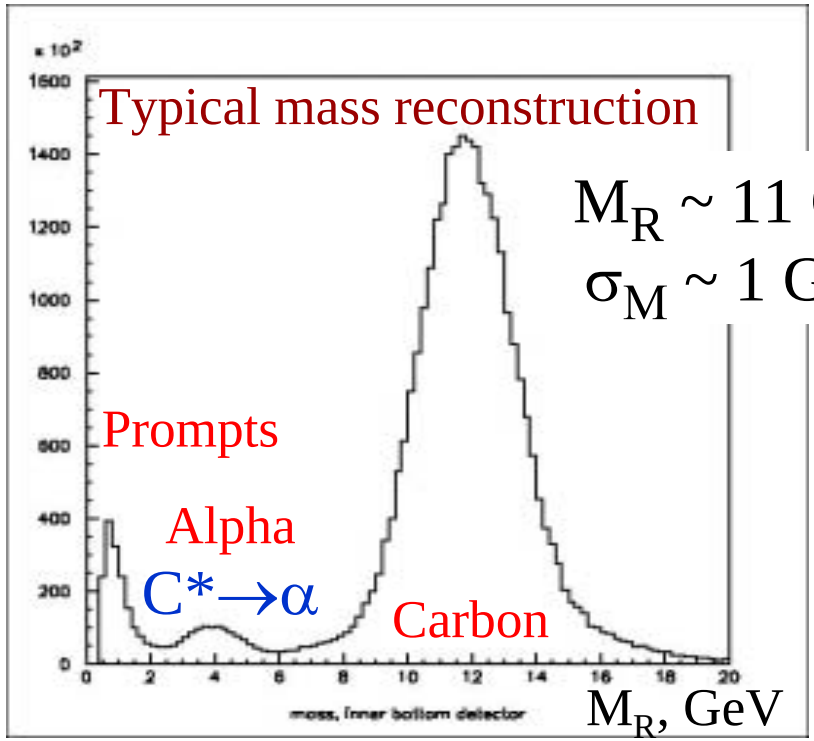
Setup for *p*C scattering – the RHIC polarimeters



- recoil carbon ions detected with Silicon strip detectors
- 2 ´ 72 channels read out with WFD (increased acceptance by 2)
- very large statistics per measurement (~ 20 ´ 10^6 events) allows detailed analysis
  - bunch by bunch analysis
  - channel by channel (each channel is an "independent polarimeter")
  - 45° detectors: sensitive to vertical and radial components of $\vec{P}_{beam}$
    → unphysical asymmetries

Event Selection & Performance





- very clean data, background < 1 % within "banana" cut
- good separation of recoil carbon from α (C* → α + X) and prompts
  may allow going to very high $|t|$ values
- Δ (Tof) < ± 10 ns (⇒ $\sigma_M \sim 1$ GeV)
- very high rate: 10^5 ev / ch / sec